**TITLE:** NOVEL ELECTRODE MATERIALS FOR LOW-TEMPERATURE SOLID-OXIDE FUEL CELLS

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## 1. ABSTRACT

### Objectives

It is the interfacial resistances that limit the performance of SOFCs at temperatures below 550°C. The overall objective of this project is to develop novel electrode materials for SOFCs to be operated at low temperatures in order to significantly reduce the cost of SOFC technology, thus, to achieve the goals of the Vision 21 coal-based power plants. More specifically, the technical objectives include (1) to characterize the microscopic features of composite mixed-conducting electrodes and correlate with the ionic, electronic, and ambipolar transport properties as well as with the catalytic activities for pertinent electrochemical reactions; (2) to minimize interfacial polarization resistances through processing modifications, microstructure improvements, and new materials development; and (3) to gain a profound understanding of the principles of composite mixed-conducting electrodes.

### Accomplishments to Date

During the current period of performance, our work was focused on the anode materials. It is proposed that fuel cell performance depends strongly on the anode microstructure, which is determined by the anode compositions and fabrication conditions. Four types of anodes with two kinds of NiO and GDC powders were investigated. By carefully adjusting the anode microstructure, the GDC electrolyte/anode interfacial polarization resistances reduced dramatically. The interfacial resistance at 600°C decreased from 1.61 $\Omega$ cm$^2$ for the anodes prepared using commercially available powders to 0.06 $\Omega$ cm$^2$ for those prepared using powders derived from a glycine-nitrate process.

The critical issues facing the development of economically competitive SOFC systems include lowering the operation temperature and creating novel anode materials and microstructures capable of efficiently utilizing hydrocarbon fuels. Anode-supported SOFCs with an electrolyte of 20 μm-thick Gd-doped ceria (GDC) were fabricated by co-pressing, and both Ni- and Cu-based anodes were prepared by a solution impregnation process. At 600°C, SOFCs fuelled with humidified $H_2$, methane, and propane, reached peak power densities of 602, 519, and 433

$mW/cm^2$, respectively. Both microstructure and composition of the anodes, as fabricated using a solution impregnation technique, greatly influence fuel cell performance.

A catalyst (1 %wt Pt dispersed on porous Gd-doped ceria) for pre-reforming of propane was developed with relatively low steam to carbon (S/C) ratio (~0.5), coupled with direct utilization of the reformate in low-temperature SOFCs. Propane was converted to smaller molecules during pre-reforming, including $H_2$, $CH_4$, CO, and $CO_2$. A peak power density of 247 $mW/cm^2$ was observed when pre-reformed propane was directly fed to an SOFC operated at 600°C. No carbon deposition was observed in the fuel cell for a continuous operation of 10 hours at 600°C.

### Future Work

The work planned for the remaining months of this research program include the following tasks:

- To fabricate anode-supported cells based on YSZ electrolyte and develop electrode materials for low-temperature operation with sulfur-containing fuels;
- To minimize interfacial polarization resistances through processing modifications, and microstructure improvements using Combustion CVD technology.

## 2. LIST OF PAPERS PUBLISHED AND STUDENTS UNDER THIS GRANT

### Journal Articles (Published)

- Nanostructured Electrodes for SOFCs Fabricated by Combustion CVD, Y. Liu, S. Zha, and M. Liu, Advanced Materials, 16 (2004) 256-260.
- Ni-GDC Anode for GDC electrolyte-Based Low-Temperature SOFCs, S. Zha, W. L. Rauch, and M. Liu, Solid State Ionics, 166 (2004) 241-250.
- Pre-reforming of Propane for Low-Temperature SOFCs, F. Chen, S. Zha, J. Dong, and M. Liu, Solid State Ionics, 166 (2004) 269-273.
- Fabrication of Nano-structured $Sm_{0.5}Sr_{0.5}CoO_{3-\delta}$ –$Sm_{0.1}Ce_{0.9}O_{2-\delta}$ Cathodes for Solid Oxide Fuel Cells Using Combustion CVD, Y. Liu, W.L. Rauch, S. Zha, and M. Liu, Solid State Ionics, 166 (2004) 261.
- Composite Cathode Based on Yttria Stabilized Bismuth Oxide for Low-Temperature SOFCs, C. Xia, Y. Zhang, and M. Liu, Appl. Phys. Lett., 82 (2003) 901-903.
- Microstructures, Conductivities, and Electrochemical Properties of GDC and GDC-Ni Anodes for Low-Temperature Sold Oxide Fuel Cells, C. Xia, and M. Liu, Solid State Ionics, 152-153 (2002) 423.
- Novel Electrode Materials for Low-Temperature Solid Oxide Fuel Cells, C. Xia, and M. Liu, Advanced Materials, 14 (2002) 521-523.
- $Sm_{0.5}Sr_{0.5}CoO_3$ Cathodes for Low-Temperature SOFCs, C. Xia, W. Rauch, F. Chen, and M. Liu, Solid State Ionics, 149 (2002) 11-19.
- Functionally Graded Cathodes for Honeycomb SOFCs, C. Xia, W. Rauch, W. Wellborn, and M. Liu, Electrochem. Solid State Letters, 5 (2002) A217-A219.
- Sulfur Tolerant Materials for Hydrogen Sulfide ($H_2S$) Solid Oxide Fuel Cell, L. Aguilar, S. Zha, S. Li, M. Liu, J. Winnick. Electrochem. Solid-State Lett., accepted.
- GDC-Based Low Temperature SOFCs Powered by Hydrocarbon Fuels, S. Zha, A. Moore, H. Abernathy, and M. Liu. J. Electrochem. Soc., accepted.

### Journal Articles (Submitted)

- Fractal Structured Nano-composite Cathodes for Low temperature Solid Oxide Fuel Cells, Y. Liu, S. Zha, M. Liu. Submitted to Chemistry of Materials.
- Functionally Graded Cathodes for SOFCs Fabricated by Sol-gel/Slurry Coating, S. Zha, Y. Zhang, M. Liu. Submitted to Solid State Ionics.

### Students Supported Under this Grant

- Ying Liu, School of Materials Science & Engineering, Georgia Tech
- Luis Aguilar, School of Chemical and Biomolecular Engineering, Georgia Tech.